Maturity Models 101: A Primer for Applying Maturity Models to Smart Grid Security, Resilience, and Interoperability

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In recent years, rapid evolutions have occurred in technology and its application in the electric power industry, leading to the introduction of many new systems, business processes, markets, and enterprise integration approaches. How do you manage the interactions of systems and processes that are continually evolving? Just as important, how can you tell if you are doing a good job of managing these changes, as well as monitoring your progress on an ongoing basis? And how do poor processes impact interoperability, safety, reliability, efficiency, and effectiveness? Maturity models can help you answer those questions by providing a benchmark to use when assessing how a set of characteristics has evolved. This paper provides a primer that explains the history of, evolution of, and applications for maturity models.

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Abstract

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Maturity models can help you answer those questions by providing a benchmark to use when assessing how a set of characteristics has evolved. This paper provides a primer that explains the history of, evolution of, and applications for maturity models.

Introduction

In recent years, rapid evolutions have occurred in technology and its application in the electric power industry. In addition, information and operational technologies have grown increasingly complex since the re-regulation of the industry in some states. That increased complexity has, in turn, led to the introduction of many new systems, business processes, markets, and enterprise integration approaches, and to the creation of many new companies offering services in these areas. As a result, many immature products and services are being consumed by companies that are themselves in states of change and that require much more inter-company electronic information exchange than ever before.

Smart grid is an evolving modernization of our nation's electricity infrastructure and a socio-technical ecosystem. Because of that, we must understand the effects of scale and the demands that ultra-large-scale systems like it will probably place on technologies and processes [Northrop 2006, p. 11].

Part of gaining that understanding involves answering these questions:

- How can you tell if you are doing a good job of managing these changes and monitoring your progress on an ongoing basis?
- How do you manage the interactions of systems and processes that are continually evolving?
- How do poor processes impact interoperability, safety, reliability, efficiency, and effectiveness?

Maturity models exist for many different challenge problems. They provide a way for organizations to approach problems and challenges in a structured way by providing both a benchmark against which to assess capabilities and a roadmap for improving them.

This paper is the first in a three-part series that will be written by the Software Engineering Institute (SEI) and the GridWise Architecture Council and will look at maturity models and smart grid. This paper provides a primer that explores

- the definition of a maturity model
- how maturity model concepts have evolved
- the benefits of using a maturity model
- the types of maturity models
- the components of a maturity model
- examples of existing and evolving maturity models
- how improving maturity brings a return on investment

What Is a Maturity Model?

In its simplest form, a *maturity model* is a set of characteristics, attributes, indicators, or patterns[1] that represent progression and achievement in a particular domain or discipline. The artifacts that make up the model are typically agreed upon by the domain or discipline and are validated through application and iterative recalibration.

A maturity model allows an organization or industry to have its practices, processes, and methods evaluated against a clear set of artifacts that establish a benchmark. These artifacts typically represent best practice and may incorporate standards or other codes of practice that are important in a particular domain or discipline.

By having the ability to benchmark, organizations can use maturity models to determine their current level of achievement or capability and then apply these models over time to drive improvement. However, when used in a broader sense, maturity models can also help organizations benchmark their performance against other organizations in their domain or industry, and help an industry determine how well it is performing by examining the achievement or capability of its member organizations.

Architecturally, maturity models typically have "levels" along an evolutionary scale that defines measurable transitions from one level to another. The corresponding attributes define each level; in other words, if an organization demonstrates these attributes, it is said to have achieved both that level and the capabilities that the level represents. Having measurable transition states between the levels enables an organization to use the scaling to

- define its current state
- determine its future, more "mature" state
- identify the attributes it must attain to reach that future state

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[1] Characteristics, attributes, indicators, or patterns are referred to generically throughout this paper as *attributes*.

For instance, in the area of Grid Operations, the Smart Grid Maturity Model (SGMM) [SEI 2012a] assesses progression from evaluating new sensors, switches, and communications technologies for grid monitoring and control, to extending use of new control analytics across line-of-business decision making, to having automated decision-making capabilities in place.

For a maturity model to be effective and have impact, the "measurable transitions" between levels should be based on empirical data that has been validated in practice; that is, each step in the model should be able to be validated as being more "mature" than the previous step against actual best practices. In essence, what constitutes "mature" behaviors must be characterized and validated, and this can be challenging to do unambiguously in many maturity model representations, if not impossible.

Thus a maturity model provides

- a place to start
- the benefit of a community's experience and knowledge
- a common language and a shared vision
- a way to define what improvement and "maturity" mean for an organization
- a framework for prioritizing actions
- a roadmap and return on investment (ROI) for increased maturity

The Early Practitioners

A staged maturity model was first applied by Richard L. Nolan of Harvard University who, in 1973, published the stages of growth model [Nolan 1973] for IT organizations. Interestingly, the areas of IT and software engineering have been behind the creation of several maturity models and are the foundations of the more well-established and comprehensive maturity models.

After Nolan's work, Watts Humphrey began developing process maturity concepts further while working at IBM. Active development of a model based on these concepts began in 1986 when Humphrey joined the SEI. The U.S. Air Force, driven by a desire to evaluate contractor capability, asked the SEI to start formalizing the Process Maturity Framework so the U.S. Department of Defense could evaluate software contractors. Humphrey based this framework on the earlier Quality Management Maturity Grid developed by Philip B. Crosby in his book *Quality Is Free: The Art of Making Quality Certain* [Crosby 1980].

In the late 1980s and early 1990s, the SEI developed the Capability Maturity Model® (CMM) framework [Paulk 1994], which captured organizational best practices for software development. The full representation of the CMM as a set of defined process areas and practices at each of its five maturity levels was initiated in 1991 with work continuing thereafter. Though the CMM comes from the area of software development, the process maturity concepts it contains can be applied generically to non-software processes, as illustrated in the CERT® Resilience Management Model (CERT-RMM) [SEI 2012b].

® Capability Maturity Model, CERT, and CMMI are registered marks owned by Carnegie Mellon University.

Ultimately, the CMM framework was superseded by the CMM Integration[SMSM] (CMMI®) [SEI 2012c] framework, which integrated models for software engineering, systems engineering, software and systems acquisition, and service delivery into a single model with a shared core. That integration helped organizations improve their investment in process improvement by reducing the need to manage the use of several models (although the subject of multi-model applications of maturity models will be addressed in the third paper in this series). In the CMMI framework, components of different maturity models are cooperatively applied with a focus on a specific area where they can each provide benefits.

Evolving the Maturity Model Concept

As mentioned earlier, the sponsors for the development of early maturity models and their users were members of the U.S. military who wanted to develop a method to objectively evaluate software subcontractors' process capability maturity. Because of the many emerging technologies, evolving standards, and suppliers of different sizes and capabilities, objective evaluations are very important in today's utility world.

In 1993, the International Standards Organization (ISO) launched its Software Process Improvement and Capability dEtermination (SPICE) Project. The purpose of SPICE was to support the development, validation, and transition of an international standard for software process assessment. The project resulted in the publication of a standard for process assessment, ISO/IEC 15504 [Loon 2004]. That model contained over 1,000 individual judgments and was criticized in the SPICE trial reports [SPICE 1998] as being too complex.

Complexity is a challenge that needs to be addressed when constructing any maturity model. A balance must be struck between having too many measures, attributes, and questions (creating laborious assessments) versus not having enough attributes to be able to make accurate and consistent assessments.

As SPICE and the CMMI framework have become more widespread and their use has significantly impacted the broad advancement of the state of practice for software and systems development, maturity models have grown in popularity. Many models have been developed for other domains and disciplines where transformative change is needed to meet challenge problems. These models have been sponsored by governments, individual organizations, and consortia (including industry-specific groups) for their own internal use or use by their customers and communities.

The level of "brain trust" that goes into these models varies, but having a broad community that can both participate in the model's design and provide solid empirical data for the establishment of best practices is clearly an advantage. The importance of peer communities will be addressed further in the next two papers in this series.

[SM] CMM Integration is a service mark owned by Carnegie Mellon University.

Benefits of Using Maturity Models

Using a maturity model as the foundation for improving processes, practices, and performance provides organizations and communities the ability to

- benchmark internal performance. Using a standard measurement approach based on the model content, organizations can determine where they are in their improvement journey and set targets for future investments in performance improvement. Different operating units in the same organization can also use the benchmark to compare performance, particularly when similar functions are performed in the operating units.
- catalyze performance improvement. By taking measurements against the model over a period of time, organizations can use the model as the basis for continuous performance improvement. And, because the model reflects the best practices of the domain or discipline, it can be used as the basis for developing action plans to close performance gaps and improve maturity.
- catalyze improvements in community performance. Because the model and measurement approach tie the community together, organizations can not only compare their performance against peer organizations but also determine a "community" performance profile. Creating such a profile may spur additional community investment in common and shared challenge problems.
- create and evolve a common language. Maturity models often create a consistent way of thinking and communicating about a domain that is embodied in model language or taxonomy. Consistent language and communication helps domains of knowledge evolve into disciplines where a common language can translate into repeatable, consistent, and predictable performance over time[2].

Model-based process improvement is greatly enabled by a consistent and repeatable measurement instrument that facilitates benchmarking against the model attributes. These instruments can be part of a well-defined and standardized measurement approach[3] or simply be embodied in a survey or questionnaire, depending on the degree of rigor required by the domain, discipline, or scenario.

Measurement instruments can range from self-applied to practitioner-applied. The latter are often preferred because they provide an independent and verifiable assessment and add rigor to benchmarks that may be relied upon for comparisons, particularly across a broad community. However, self-application can be very powerful and cost-effective for internal process improvement.

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[2] Consider the medical field: Broad advances could only have been possible if the language of the discipline was consistent and known by all practitioners. As a result, when a doctor refers to a "spine," it is common knowledge to all in the profession exactly what part of the body is being referred to.

[3] The Standard CMMI Appraisal Method for Process Improvement (SCAMPI[SM] method) is a standardized measurement methodology developed by the SEI. It is required for assigning a maturity level against any CMMI model. Practitioners (called "Lead Appraisers") are taught how to use the methodology and are certified and licensed to perform appraisals. (SCAMPI is service mark of Carnegie Mellon University.)

Types of Maturity Models

In general, maturity models can be categorized as one of the following three types:[4]

- progression models
- capability models
- hybrid models

Progression Models

Progression maturity models represent a simple progression or scaling of a characteristic, indicator, attribute, or pattern where the movement up the maturity levels indicates some progression of attribute maturity. This category includes many proprietary models developed by companies such as consultancies or product vendors.

Progression models can be measured independently and are typically characterized by a focus on the model attributes rather than attributes that specifically define maturity. In other words, the purpose of a progression model is to provide a roadmap of progression or improvement as expressed by increasingly better versions of an attribute as the scale progresses. For example, a maturity progression for counting might be

pencil and paper → abacus → calculator → computer

In addition, in progression models, the maturity levels are often labeled relative to a "state" or "step" in the progression. In the counting example, level one might be expressed as "primitive," and level 3 might be expressed as "tool-enabled."

One caution to note is that progression models are often described as "cast in the mold of a capability maturity model" when in fact they do not measure capability or process maturity (which is a foundational concept in those models).

The Smart Grid Maturity Model is an example of a progression model.

Capability Maturity Models

In a capability maturity model, the dimension that is being measured is a representation of organizational capability around a set of characteristics, indicators, attributes, or patterns, often expressed as "processes." (Hence, that is why capability maturity models are often synonymously referred to as "process models.") This is important because it measures more than the ability to perform a simple (or complex) task. In addition, it looks at a broader organizational capability that reflects the maturity of the culture and the degree to which the capabilities are embedded (or "institutionalized") in the culture. Thus, the "levels" in a capability maturity model describe states of organizational maturity relative to process maturity such as

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[4]   Caralli, Rich. *Discerning the Intent of Maturity Models from Characterizations of Security Posture*, 2012.

ad hoc → managed → defined → quantitatively   managed → optimized

Because of the generic nature of the process maturity scaling, the basic maturity carriage of the CMMI framework can be applied to other domains, such as service management and operational resilience. As a result, models like CMMI for Services and CERT-RMM have emerged to take advantage of this time-proven means for improving performance.

Hybrid Models

Overlaying characteristics of the progressive model with capability attributes from capability maturity models can create a hybrid maturity model. This type of model reflects transitions between levels that are similar to a capability model (i.e., that describe capability maturity) but architecturally use the characteristics, indicators, attributes, or patterns of a progression model. While they make the hybrid model very useful for focusing on specific subject matter domains, those differences assess maturity from the perspective of how well standards and best practices have been included into the organization's capabilities. This institutionalization of capability creates models that are relatively easy to use and understand, have great value, and can be used as a roadmap to improved maturity. In other words, hybrid models provide the rigor of a capability maturity model while embracing the ease of use and comprehensibility of progression models.

One example of a hybrid model is the Electricity Subsector Cybersecurity Capability Maturity Model (ES-C2M2) [SEI 2012d], which was developed by applying the capability maturity concepts in CERT-RMM to existing codes of practice in the energy sector.

The Smart Grid Interoperability Maturity Model [GWAC 2012] developed by the GridWise Architecture Council is another example of a hybrid model. It applies the concepts of stakeholder information exchange capability in the National E-Health Transition Authority (NEHTA) [NEHTA 2007] to smart grid interface specifications. It does so using the interoperability context setting framework [GWAC 2008] to explore different levels (technical, informational, organizational) of interoperability maturity as it applies to different crosscutting issues.

Some of the maturity models mentioned in this section will be discussed in more detail in the next paper in this series. To read more about them now, see the References at the end of this paper.

Essential Components of a Maturity Model

Despite the differences in types of maturity models, most of them conform to some structural basics. This structure is important because it provides a linkage between objectives, assessments, and best practices, and it facilitates relationships between current capabilities and improvement roadmaps by linking them to business goals, standards, and so forth.

Levels

As previously discussed, levels represent the transitional states in a maturity model. Depending on the model architecture, the levels may describe a progressive step or plateau, or they may represent an expression of capability or other attribute that can be measured by the model.

Model Domains

Domains are a means for grouping like attributes into an area of importance for the subject matter and intent of the model. In capability maturity models, the domains are referred to as "process areas" because they are a collection of processes that make up a larger process or discipline (such as software engineering). Depending on the model, users may be able to focus on improving a single domain or a group of domains. Some models, such as the CMMI framework, might contain a representation that requires a prescribed progression through the domains in order to achieve the intended result.[5]

Attributes

Attributes represent the core content of the model grouped together by domain and level. They are typically based on observed practice, standards, or other expert knowledge, and can be expressed as characteristics, indicators, practices, or processes. In the case of a capability maturity model, attributes may also express qualities of organizational maturity (such as planning) that are important for supporting process improvement (regardless of the process being modeled).

Appraisal and Scoring Methods

Appraisal and scoring methods are developed to facilitate assessment using the model as the basis. They can be formal or informal, expert-led or self-applied. Scoring methods are algorithms devised by the community to ensure consistency of appraisals and a common standard for measurement. Scoring methods can include weighting (so that important attributes are valued over less important ones) or can value different types of data collection in different ways (such as providing higher marks for documented evidence as opposed to interview-based data).

Improvement Roadmaps

In addition to being used for benchmarking, maturity models can be used to guide improvement efforts. Many of these models have prescribed methods for identifying an improvement scope, diagnosing current state, and then planning and implementing improvement and verifying that it has occurred. These methods define a classic plan-do-check-act (PDCA) cycle into which a maturity model fits as the basis for the improvement [Shewhart 1986, p. 45; Deming 1952]. The IDEAL[SM] model is a reference model for using the CMMI framework in a PDCA cycle.[6]

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[5] The CMMI framework contains *continuous* and *staged* model representations. Continuous representations enable consideration of an individual process area and the measurement of capability within it. With staged representations, a prescribed path through the process areas is required, process areas are grouped together, and, as capability improves across the group, an expression of organizational maturity can be made.

[SM] IDEAL is a service mark of Carnegie Mellon University.

[6] For more information on the IDEAL model, go to http://www.sei.cmu.edu/library/abstracts/reports/96hb001.cfm.

Moving Forward

This paper is intended to introduce the topic of maturity models and position these models as a primary tool in addressing the security, interoperability, and resilience challenges facing the energy sector and its related communities. The history of maturity models and their ability to transform the state of the practice is well established and validated in the software engineering discipline, and these lessons are being translated into more operational domains such as service delivery and operational resilience management.

Because maturity models can have transformative powers, this paper is the first in a series that explores how well-constructed maturity models can affect the future of the energy sector. In future papers, we will explore topics in more detail such as

- the current landscape of maturity models in the energy sector and their harmonization
- exploration of specific models such as the SGMM and the Smart Grid Interoperability Maturity Model (SG-IMM), and how they are transforming their respective domains
- multi-model approaches for selecting and harmonizing the best aspects of different models for specific challenge problems, while keeping model fatigue at a minimum
- making the business case for investing in and using a maturity model for improvement

Author Biographies

Richard Caralli is the technical director of the CERT Cyber Enterprise and Workforce Management Directorate in the CERT Program at the Software Engineering Institute (SEI). Caralli is responsible for setting and executing the strategic plan for a research portfolio focused on improving the security and resilience of organizational assets, including people, information, technology, facilities, and infrastructures. Previously, Caralli was the lead architect of the CERT® Resilience Management Model, a process improvement-focused maturity model for managing operational resilience, and has spent over 10 years developing and delivering various information security risk assessment, analysis, and management technologies for customers in the federal government and the private sector. Prior to joining CERT in 2001, Caralli was the Manager – IT Audit at Consolidated Natural Gas (now Dominion Resources) and the project manager of CNG's global Y2K project. Caralli is an adjunct instructor in Carnegie Mellon's Heinz College CIO Institute and the Information Networking Institute, lecturing in information security risk management and the economics of information security. Caralli holds a BS degree in Accounting from St. Vincent College and an MBA from the John F. Donahue Graduate School of Business at Duquesne University.

Mark Knight is an executive consultant in CGI's US Enterprise Markets Business Unit and is a member of the GridWise Architecture Council. Knight draws on 25 years of experience to deliver business solutions that enhance operations and business practices for utilities to support innovative, effective, and practical solutions for CGI's clients. Knight's background includes a mix of information technology work and business process work both as a consultant and as a utility employee in the UK and North America. His experience spans several areas including distribution, transmission, metering, systems integration, deregulation, interoperability, asset

management, and risk management. Knight is a graduate of Imperial College, London and was part of the team that developed the Smart Grid Interoperability Maturity Model.

Austin Montgomery is the Smart Grid Program lead for the Software Engineering Institute (SEI), a unit of Carnegie Mellon University in Pittsburgh, PA. The SEI collaborates with government and industry to address security, architecture, interoperability, process improvement, and other software and systems engineering challenges of grid modernization. Montgomery spent the first part of his career as a merger and acquisition attorney, investment banker, and management consultant. Prior to joining the SEI, he was a founder and senior executive of several start-up companies that developed innovative software and wireless communication technologies. He received a BA in economics from Harvard University, a JD from the University of California, Hastings College of the Law, and an MBA from the Simon School of the University of Rochester and the Erasmus University in the Netherlands.

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